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**CURRENCY CRISES, MONETARY POLICY, AND CORPORATE  
BALANCE SHEET VULNERABILITIES**

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# Currency Crises, Monetary Policy, and Corporate Balance Sheet Vulnerabilities\*

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## Abstract

This paper studies how the exposure of a country's corporate sector to interest rate and exchange rate changes affects the probability of a currency crisis. To analyze this question, we present a model that defines currency crises as situations in which the costs of maintaining a fixed exchange rate exceed the costs of abandonment. The results show that a higher exposure to interest rate changes increases the probability of crisis through an increased need for output loss compensation and an increased efficacy of monetary policy in stimulating output. A higher exposure to exchange rate changes also increases the need for output loss compensation. However, it lowers the efficacy of monetary policy in stimulating output through the adverse balance sheet effects of exchange rate depreciation. As a result, its effect on the probability of crisis is ambiguous.

Keywords: Currency Crises; Monetary Policy; Short-Term Debt; Foreign Debt; Corporate Balance Sheets

JEL classification: E52; E58; F34

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# 1 Introduction

During the last three decades, many countries and regions around the world have suffered from currency crises.<sup>1</sup> Their origin remains the source of much controversy. From an academic perspective, an extensive economic literature has evolved, both theoretical and empirical.

The theoretical literature on currency crises started with the works of Krugman (1979) and Flood and Garber (1984), which are now often referred to as ‘first-generation models of currency crises’.<sup>2</sup> These models were developed in response to crises in Latin America in the 1970s and early 1980s, which were characterized by preceding periods of overly expansive budgetary policies combined with fixed exchange rate regimes. The models show how the monetary financing of structural government deficits leads to a gradual depletion of the central bank’s foreign reserves, as the central bank stands ready to buy the excess domestic money in return for foreign money. At some point in time, a speculative attack occurs which wipes out the central bank’s remaining stock of foreign reserves and leads to a collapse of the fixed exchange rate regime.

Although well explaining the early crises in Latin America, first-generation models suffered from some weaknesses. This became particularly apparent after the crisis in the European Monetary System (EMS) in 1992 and 1993, which was not preceded by structural government deficits or a gradual depletion of foreign reserves. Instead, governments widened their exchange rate bands due to sudden severe speculative attacks on their currencies. This raised questions on whether the crises could be explained solely by fundamentals or whether speculative attacks contained self-fulfilling features. In response to these questions, a new strand of ‘second-generation’ or ‘escape clause’ models emerged.<sup>3</sup> These models show that if policymakers face a trade-off between exchange rate stability and other objectives, such as employment during the EMS crisis, the future level of the exchange rate may be subject to multiple equilibria<sup>4</sup>. If the market does not expect a devaluation, the

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<sup>1</sup>Examples include Mexico (’73-’82), Argentina (’78-’81), Europe (’92-’93), again Mexico (’94-’95), East Asia (’97-’98), Russia (’98), Brazil (’99), and most recently, Turkey (’00-’01) and Argentina (’01-’02).

<sup>2</sup>Other contributions include Blanco and Garber (1986), Dornbusch (1987), Obstfeld (1984), Willman (1988), Van Wijnbergen (1991), Wyplosz (1986), and Edwards and Montiel (1989). A survey is provided by Agénor *et al.* (1992).

<sup>3</sup>Examples include Obstfeld (1986, 1994, 1996, 1997), Cole and Kehoe (1996), Jeanne (1997a, 1997b), Jeanne and Masson (2000), and Bensaid and Jeanne (1997). The latter study mentions several reasons for why raising the interest rate is costly, one of which refers to the ‘weakening of the financial and banking system’, and is therefore also sometimes referred to as a third-generation model. For a survey of second-generation or escape clause models, see Rangvid (2001), Flood and Marion (1999), Jeanne (2000), and Saxena (2004).

<sup>4</sup>The existence of multiple equilibria is most often identified as the key characteristic of second-generation literature, as in for example De Grauwe (1997). Other characterizations include the presence

costs of maintaining a fixed exchange rate remain low and the policymakers choose to hold on to it. However, if market participants do expect a devaluation, this expectation can become self-fulfilling because it increases the costs of maintenance by forcing policymakers to raise the interest rate.

Although first- and second-generation models have done reasonably well in explaining many past crisis episodes, they do not seem to fully explain the more recent crisis in East Asia ('97-'98). These countries did not experience any first-generation like fiscal problems nor did they face the policy trade-off between exchange rate stability and unemployment, as some EMS crisis countries did. Hence, new models were needed and the first attempts to develop such models focused on problems in the banking sector. Krugman (1998a) and Corsetti *et al.* (1999) argued that implicit government guarantees led to moral hazard and an excessive level of investment, which after some time collapsed when governments were no longer willing or able to cover the losses. Chang and Velasco (1998) focused on a shortage of liquidity in the banking system caused by a loss of confidence amongst investors, analogue to the classic bank run in Diamond and Dybvig (1983). However, it was not long until a new strand of literature emerged. This literature, sometimes referred to as 'third-generation literature', stresses the importance of balance sheet vulnerabilities and international capital flows.<sup>5</sup>

Balance sheet crisis literature has seen two classes of models (Jeanne and Zettelmeyer, 2002). The first class of models considers a combination of currency and maturity mismatches on banks' balance sheets, where crises are characterized by runs on short-term foreign currency debt. The second class of models only considers a currency mismatch in corporate balance sheets, where crises are characterized by a credit crunch and a drop in investment.<sup>6</sup> In both cases, crises can be self-fulfilling, as the depreciation of the real exchange rate inflates foreign currency debt on balance sheets, which has severe adverse effects that validate prior crisis expectations.

Krugman (1998b) also stresses the importance of corporate balance sheet vulnerabilities in relation to high interest rates: *"Mexico was able to go through a year of interest rates that ran as high as 75% and survive. Asia's economies, it turned out, were more vulnerable because their corporations were much more highly leveraged. When your debt is four or five times your equity—an unheard-of ratio in the West but standard practice in South Korea—it*

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of an optimizing policymaker, as in Isard (1995) and Sutherland (1995), and the endogeneity of exchange rate policy, as in Cavalleri and Corsetti (1996) and Buiter *et al.* (1998).

<sup>5</sup>This notion was first put forward by Dornbusch (1999) and Krugman (1999) to explain the East Asian crisis, where corporate balance sheets were fragile, and the 1995 Mexican and 1999 Brazilian crises, where governments' balance sheets were fragile.

<sup>6</sup>For the first class of models see for example Chang and Velasco (2000), Burnside *et al.* (2001a, 2001b, 2004), and Jeanne and Wyplosz (2001). For the second class, see Krugman (1999), Aghion *et al.* (2000, 2001, 2004), and Schneider and Tornell (2004).

*doesn't take very long for recession plus high interest rates to wipe you out.*" (Krugman, 1998b, p. 27-32).

This paper studies how the exposure of a country's corporate sector to interest rate and exchange rate changes affects the probability of a currency crisis. To analyze this question, we present a model that defines currency crises as situations in which the costs of maintaining a fixed exchange rate exceed the costs of abandonment. The costs of maintenance and abandonment in our model arise from deviations of output and inflation from their desired levels. The model allows us to study the impact of high corporate exposures on these deviations of output and inflation and thus on the probability of a currency crisis.<sup>7</sup>

The results show that a higher corporate exposure to *interest rate changes* increases the risk premium that corporates have to pay on external funds. This higher risk premium depresses investments and output and hence makes it more costly for the monetary authorities to maintain the fixed exchange rate. In addition, a higher corporate exposure to interest rate changes also makes monetary policy more effective in stimulating output. This is because corporates are more heavily exposed to interest rates and an interest rate cut thus has a larger negative effect on the risk premium through improved corporate balance sheet positions. A higher exposure to interest rate changes thus increases both the need for output loss compensation and the efficacy of monetary policy in stimulating output. These two effects create incentives for the monetary authorities to abandon the fixed exchange rate. Hence, a higher exposure to interest rate changes increases the probability of an abandonment of the fixed exchange rate (currency crisis).

By contrast, the sign of the effect of a higher corporate exposure to *exchange rate changes* is shown to be ambiguous. On the one hand, a higher corporate exposure to exchange rate changes also increases the costs of maintenance by raising the risk premium that firms pay on external funds. However, whereas higher domestic debt makes monetary policy more effective in stimulating output, higher foreign debt has the opposite effect. Abandonment of the fixed exchange rate and a loosening of monetary policy lead to a depreciation of the nominal exchange rate. Given the higher corporate exposure to exchange rates, this depreciation has larger adverse effects on the risk premium and thus on output. A higher exposure to exchange rate changes thus increases the need for output loss compensation but lowers the efficacy of monetary policy in stimulating output through the adverse balance sheet effects of exchange rate depreciation. As a result, the sign of the net effect of a higher exposure to exchange rate changes on the probability of an abandonment of the fixed exchange rate (currency crisis) is ambiguous.

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<sup>7</sup>Studies with a similar focus on output and inflation costs include Obstfeld (1994) and Obstfeld (1996). These studies stress the role of self-fulfilling inflationary expectations on the monetary authorities' commitment to the fixed exchange rate. This paper instead focuses on the role of corporate balance sheet vulnerabilities in eroding the commitment to the fixed exchange rate.

## 2 The model

We use an extended version of the Dornbusch (1976) sticky-price monetary model for the exchange rate to study a small open economy that initially runs a fixed exchange rate. The model has three periods. In period  $t-1$ , the monetary authorities are credibly committed to the fixed exchange rate and the economy is in long-run equilibrium. In period  $t$ , they either maintain the fixed exchange rate or abandon it. Prices are sticky throughout this period and the economy can temporarily deviate from its long-run equilibrium. Finally, in period  $t+1$ , prices adjust and the economy returns to long-run equilibrium with either a fixed or a floating exchange rate, depending on the monetary authorities' decision in period  $t$ .

We assume that, if the monetary authorities maintain the fixed exchange rate in period  $t$ , market participants will expect them to maintain it throughout period  $t+1$  as well. Only if the monetary authorities abandon the fixed exchange rate in period  $t$ , market participants' expectations adjust and will be reflected in the period  $t+1$  price level.

The model assumes the following conditions to hold in period  $t$ . All variables are in logarithms<sup>8</sup> and symbols that are marked by asterisks refer to the foreign country and are assumed exogenous.<sup>9</sup>

$$M_t - \bar{p}_t = \gamma - \beta (i_t - RP_t) \quad (1)$$

$$y_t = y_n - \lambda (r_t - r_n) + \theta (S_t - \bar{p}_t) \quad (2)$$

$$r_n = r^* = i^* = c \quad (3)$$

$$i_t = i^* + (S_{t+1} - S_t) + RP_t \quad (4)$$

$$S_{t+1} = p_{t+1} \quad (5)$$

$$\dot{i}_t = r_t + \dot{p}_{t+1} \quad (6)$$

where  $M_t$  is the domestic nominal money supply,  $\bar{p}_t$  is the domestic price level (fixed),  $i_t$  is the domestic nominal interest rate,  $RP_t$  is the default risk premium in the home country relative to the foreign country,  $y_t$  and  $y_n$  denote the actual and natural level of domestic real output, respectively,  $r_t$  and  $r_n$  denote the actual and natural level of the domestic real interest rate, respectively,  $r^*$  is the foreign real interest rate (fixed),  $S_t$  is the nominal exchange rate defined as the price of foreign currency in terms of home currency,  $i^*$  is the

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<sup>8</sup>Hereafter, we use a circumflex to denote the non-logarithmic form of the variables (e.g.  $\hat{M}_t$ ), unless mentioned otherwise.

<sup>9</sup>Since we study a small open economy, we assume that the foreign interest rates are exogenous. The foreign country in our model represents the anchor country to which the home country has fixed its exchange rate.

foreign nominal interest rate (fixed) and  $\dot{p}_{t+1}$  is period  $t+1$  inflation ( $= p_{t+1} - \bar{p}_t$ ).<sup>10</sup>  $\gamma$ ,  $\beta$ ,  $\lambda$ ,  $\theta$ , and  $c$  are strictly positive constants.

Equation (1) represents equilibrium in the domestic money market. We assume demand for real money to depend on the expected return on domestic assets, which equals the nominal return  $i_t$  minus the risk premium  $RP_t$ .<sup>11</sup> Equation (2) denotes goods market equilibrium. Deviations of the real interest rate from its natural level and the exchange rate from its purchasing power parity (PPP) level<sup>12</sup> may cause a deviation of output from its natural level. The former reflects the negative effect of higher interest rates on investment as part of aggregate demand. The latter reflects the positive effect of a real exchange rate depreciation on the current account in the short-run. Equation (3) states that the natural real interest rate equals the (fixed) foreign real interest rate, which we assume to be constant and equal to the nominal foreign interest rate (i.e. inflation in the foreign country is zero). Equation (4) shows a revised version of the uncovered interest rate parity condition. We assume imperfect substitutability of domestic and foreign assets. We think of this as reflecting differences in default risk, which require a risk premium (section 2.2.1). As in period  $t+1$  the economy is in long-run equilibrium, the expected  $t+1$  exchange rate in period  $t$  equals the actual exchange rate in period  $t+1$ . I.e., once market participants are informed about the decision of the monetary authorities in period  $t$ , they have perfect foresight as to the period  $t+1$  price level and, hence, the period  $t+1$  exchange rate (purchasing power parity). Equation (5) represents the assumption of purchasing power parity in period  $t+1$ . Equation (6) illustrates that the nominal interest rate in period  $t+1$  equals the sum of the real interest rate and the level of inflation in period  $t+1$ .

## 2.1 Financial fragility and the risk premium

We assume the risk premium on domestic assets to depend on the degree of financial fragility in the economy. In our model, financial fragility relates to the state of the balance sheets in the corporate sector. In particular, we define financial fragility as the degree to which the net worth of the corporate sector is vulnerable to increases in the domestic interest rate and/or devaluations of the currency. Higher financial fragility therefore corresponds to higher levels of (consolidated<sup>13</sup>) domestic currency short-term debt (domestic debt) and/or higher levels of (consolidated) foreign currency debt (foreign debt).

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<sup>10</sup> $i_t$ ,  $RP_t$ ,  $r_t$ ,  $r_n$ ,  $r^*$  and  $i^*$  are short notations for  $(1 + i_t)$ ,  $(1 + RP_t)$ ,  $(1 + r_t)$ ,  $(1 + r_n)$ ,  $(1 + r^*)$  and  $(1 + i^*)$ , respectively.

<sup>11</sup>Section 2.2.1 explains the determinants of the risk premium in our model.

<sup>12</sup>The log of the foreign price level is assumed to be zero.

<sup>13</sup>We assume the supply side of the domestic economy to consist of a positive number of identical firms. The equations hereafter not only apply to firms at the individual level but also refer to the entire economy at the consolidated level.



The microeconomic underpinning of the risk premium that we use in our model follows from Céspedes *et al.* (2004) and Bernanke *et al.* (2000). They assume asymmetric information between borrowers and lenders of capital. Borrowers have complete insight into the returns of investments whereas lenders cannot observe these returns unless they pay a proportional monitoring cost. Referring to Williamson (1987), the authors assume a debt contract with a fixed repayment. As long as borrowers pay off their debt, lenders have no incentive to monitor the realized return on investment. However, if borrowers renege on the debt contract, lenders will monitor the outcome and claim the whole return on investment. The question of whether borrowers can meet their obligations depends on the realized return on investment, which Céspedes *et al.* assume to be independently and identically distributed. Given the level of debt and the required return on this debt, one can determine a minimum threshold level of the realized return for which the borrower is still able to pay off his debt. If the realized return falls short of this minimum level, bankruptcy will follow shortly thereafter and the lender will have to incur monitoring costs. These possible costs of monitoring give rise to the existence of a risk premium on debt titles. The level of these expected monitoring costs is shown to be depending on the level of investment relative to the level of net worth of the borrower. The higher the proportion of net worth in total investment, the lower the part of the investment that is externally financed, and the lower the minimum threshold value of the realized return for which the borrower can still repay his debt. Hence, higher net worth is associated with a lower probability of bankruptcy, lower expected monitoring costs and therefore a lower risk premium. Formally, we assume that the risk premium is given by:

$$\begin{aligned} \ln Risk Premium_t &= \ln \left( \frac{Investment_t}{Net Worth_t} \right) \\ &= \ln Investment_t - \ln NetWorth_t \end{aligned} \quad (7)$$

All variables in non-logarithmic forms.

Equation (2) showed that the level of (real) investment is negatively related to the deviation of the real interest rate from its natural level. For simplicity, we assume the level of investment in (7) to be given by:

$$\ln Investment_t = \psi - \delta (r_t - r_n) \quad (8)$$

where  $\psi$  and  $\delta$  are positive constants.

Net worth is given by:

$$\ln Net Worth_t = \ln (\hat{\phi}_t - \hat{r}_t \hat{d}_t^d - (\frac{\hat{S}_t}{\hat{S}^{fix}}) \hat{d}_t^f) \quad (9)$$

where  $\hat{\phi}_t$  is the level of consolidated total assets at the beginning of period  $t$  (equal to the sum of debt and net worth),  $\hat{d}_t^d$  is the level of consolidated domestic debt at the beginning of period  $t$ , maturing in 1 period,  $\hat{S}^{fix}$  is the level of the fixed exchange rate at the beginning of period  $t$ , and  $\hat{d}_t^f$  is the level of consolidated foreign debt at the beginning of period  $t$ .

Equation (9) shows that net worth in period  $t$  depends on the levels of the real interest rate and the real exchange rate<sup>14</sup>. First, a higher real interest rate - which is assumed to be under control of the monetary authorities - increases debt service obligations for borrowers. As a result, the real present value of debt increases and, for a given value of total assets, the level of real net worth falls. Second, a devaluation of the real exchange rate also lowers net worth, as the real domestic currency value of foreign currency debt increases.

Substituting (8) and (9) into (7) yields the following for the domestic risk premium:

$$\ln \text{ domestic risk premium}_t = \psi - \delta(r_t - r_n) - \ln(\hat{\phi}_t - \hat{r}_t \hat{d}_t^d - (\frac{\hat{S}_t}{\hat{S}^{fix}}) \hat{d}_t^f) \quad (10)$$

For simplicity, we assume that in the foreign country the real exchange rate equals its long-run equilibrium level and that domestic and foreign debt are zero, which yields the following for the foreign risk premium:

$$\ln \text{ foreign risk premium}_t = \psi - \ln \hat{\phi}_t \quad (11)$$

The relative risk premium,  $RP_t$ <sup>15</sup>, can be found by subtracting (11) from (10):

$$\begin{aligned} RP_t &= \ln \text{ domestic risk premium}_t - \ln \text{ foreign risk premium}_t \\ &= -\delta(r_t - r_n) - \ln(1 - \hat{r}_t \frac{\hat{d}_t^d}{\hat{\phi}_t} - (\frac{\hat{S}_t}{\hat{S}^{fix}}) \frac{\hat{d}_t^f}{\hat{\phi}_t}) \end{aligned} \quad (12)$$

Using the approximation  $\ln(1+x) \approx x$  we can rewrite (12) as:

$$RP_t = -\delta(r_t - r_n) + \hat{r}_t \frac{\hat{d}_t^d}{\hat{\phi}_t} + (\frac{\hat{S}_t}{\hat{S}^{fix}}) \frac{\hat{d}_t^f}{\hat{\phi}_t} \quad (13)$$

With the same approximation,  $\hat{r}_t$  can be written as  $(1 + r_t)$  and  $(\frac{\hat{S}_t}{\hat{S}^{fix}})$  can be rewritten as  $(1 + S_t - S^{fix})$ :

$$RP_t = -\delta(r_t - r_n) + (1 + r_t) \frac{\hat{d}_t^d}{\hat{\phi}_t} + (1 + S_t - S^{fix}) \frac{\hat{d}_t^f}{\hat{\phi}_t} \quad (14)$$

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<sup>14</sup>The level of the fixed exchange rate equals the period  $t$  price level as market participants expected the fixed exchange rate to be maintained. Therefore, under maintenance PPP must hold.

<sup>15</sup>Recall that  $RP_t$  denotes the logarithm of  $(1+RP_t)$ , where  $RP_t$  denotes the default risk premium on domestic debt relative to foreign debt in period  $t$ .

## 2.2 The monetary authorities

We assume that, prior to period  $t$ , the monetary authorities have been maintaining a fixed exchange rate regime. This implies that any change in the nominal interest rate - needed to maintain the equality in (4), given the fixed exchange rate - is automatically facilitated by an adjustment of the money supply. If, for example, the foreign interest rate rises, market participants will want to sell domestic assets, exchange the receipts for foreign currency and buy foreign assets. Under a floating exchange rate, this would cause a depreciation of the home currency. Under a fixed exchange rate, the monetary authorities stand ready to buy the excess supply of domestic currency in return for foreign currency. As a result, foreign reserves drop and the domestic money supply falls. The resulting higher domestic interest rate restores the equilibrium in (4) and, hence, safeguards the fixed exchange rate. Since monetary policy has to ensure the fixed value of the currency, it is no longer autonomous and cannot be used to stimulate output.

However, the fixed exchange rate regime is not irreversible. We assume that the maintenance of a fixed exchange rate is a matter of trade-off. As long as the costs of maintenance do not exceed the costs of abandonment of this regime, the authorities choose to maintain the fixed value. If this is no longer the case, they abandon the peg and allow the exchange rate to float. The costs of maintenance and abandonment are dependent on the monetary authorities' preferences, which are modeled by the following loss function for period  $t$  (all variables in logarithms, except for  $\chi$  and  $\eta$ ):

$$L_t^{CB} = \frac{\chi}{\eta} \dot{p}_{t+1}^2 + (y_t - y_n - k)^2 \quad (15)$$

where  $\chi$  is the relative weight put on price stabilization (degree of conservativeness of the monetary authorities),  $\eta$  is the monetary authorities' rate of time preference<sup>16</sup>, and  $k$  is the positive wedge between the output level targeted by the monetary authorities and the natural output level. All three variables are assumed to be strictly positive.

We assume the monetary authorities to care about inflation and output. Since we assume inflation in period  $t$  and  $t-1$  to be zero, costs of inflation can only arise from possible non-zero inflation in period  $t+1$ . The importance of the costs of inflation depends on both the conservativeness and the rate of time preference of the monetary authorities.

The output costs stem from possible deviations of output from the monetary authorities' desired level,  $y_n + k$ . Since output in period  $t-1$  and  $t+1$  equals its natural level and cannot be influenced by the monetary authorities, we only include period  $t$  output in the loss function. Possible rationales for the positive wedge  $k$  between the desired output level and the natural output level are the existence of political business cycles or an imperfectly

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<sup>16</sup>  $\eta$  is short notation for  $(1 + \eta)$ .

functioning labour market.

We assume that the monetary authorities decide in period  $t$  on whether or not to maintain the fixed exchange rate. If they do, the fixed exchange rate is maintained throughout period  $t$  and period  $t+1$ . If they do not, the peg is abandoned. We assume that in case of abandonment, the exchange rate is allowed to float and the monetary authorities cannot credibly commit to a new peg or any intermediate exchange rate regime.

The trade-off between costs of maintenance and costs of abandonment closely relates to the literature on rules and discretion in monetary policy. In particular, the ‘temptation’ to stimulate output above its natural level versus the ‘enforcement’ through higher future inflation was first introduced by Barro and Gordon (1983).

### 3 Solving the model

To solve the model we first derive the discretionary equilibrium, that is the long-run equilibrium under a floating exchange rate regime, which yields us the rate of inflation under floating. We then consider an initially fixed exchange rate regime and derive two alternative equilibria: the equilibrium under maintenance of the fixed exchange rate in period  $t$  and the equilibrium under abandonment of the fixed exchange rate in period  $t$ . Finally, we compare the monetary authorities’ payoffs under both equilibria to determine the conditions under which the peg is abandoned, i.e. to identify the determinants of currency crises.

#### 3.1 Discretionary equilibrium

Under a floating exchange rate and in long-run equilibrium, we assume market participants to fully anticipate monetary policy. We also assume that they can set prices in accordance, ensuring that output does not deviate from its natural level. Since the desired output for the monetary authorities exceeds the natural output level, they have an incentive to use monetary policy to lift output above the natural level. Market participants foresee this and set prices accordingly. The result is positive inflation without any output gain, i.e. an inflationary bias. We define this inflationary bias as  $\pi^n$ , which could be understood as ‘the natural rate of inflation’ under rational expectations.

Appendix 1 shows the derivation of the discretionary equilibrium. The optimal level of the money supply is shown to be:

$$M_t = M_{t-1} + \frac{X}{\frac{\chi}{\eta}} \cdot k \quad (16)$$

$$\text{where } X = (\lambda + \theta) \left( \frac{1 + \beta}{\beta} \right)$$

with the inflationary bias being:

$$\pi^n = \frac{X}{\left( \frac{\chi}{\eta} \right)} \cdot k \quad (17)$$

The inflationary bias is positively depending on  $\lambda$  and  $\theta$  because these coefficients imply the efficacy of activist monetary policy through the ‘interest rate’ and ‘exchange rate’ channels, respectively. The inflationary bias is negatively depending on  $\beta$ , which indicates the inverse of the impact of money supply changes on the level of the interest rate. Higher levels of  $\beta$  correspond to a lower impact of monetary loosening on the interest rate and reduce the monetary authorities’ incentive to cheat. The inflationary bias decreases with the monetary authorities’ degree of conservativeness,  $\chi$ , as inflation becomes more costly. A higher rate of the monetary authorities’ time preference,  $\eta$ , leads instead to a higher inflationary bias, as the costs of inflation decrease in present value terms. Finally, the positive wedge  $k$  between the monetary authorities’ desired output level and the natural output level, which is the root cause of the inflationary bias, has a positive effect on its size.

## 3.2 Equilibria under an initially fixed exchange rate

We now derive the equilibria under maintenance and abandonment of the fixed exchange rate regime. We assume the exchange rate to be fixed throughout period  $t-1$  and the economy to be in long-run equilibrium in period  $t-1$ . As explained earlier, we assume the peg to be credible, i.e. market participants set period  $t$  prices in accordance with their expectation that the fixed exchange rate will be maintained in period  $t$ . However, we allow for deviations of domestic and foreign debt levels from their equilibrium values, which changes the monetary authorities’ trade-off. If the monetary authorities decide to maintain the peg, the economy remains in long-run equilibrium in period  $t$ . If they decide to abandon the peg, there will be a temporary deviation from long-run equilibrium. We consider the conditions under which abandonment (‘currency crisis’) takes place and, in particular, how the levels of debt relate to this possible abandonment.

### 3.2.1 Maintenance of the fixed exchange rate

Appendix 2A shows the derivation of the equilibrium in case of maintenance of the fixed exchange rate throughout period  $t$ . The costs of maintenance are shown to be equal to:

$$L_t^{CB} = \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\hat{\phi}_t} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t} \right)}{\left( 1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)} \right) + k \right)^2 \quad (18)$$

If debt levels equal their natural levels, the costs of maintenance simply equal  $k^2$ . Equation (18) shows how deviations of the domestic and foreign debt levels increase the costs of maintaining a fixed exchange rate. Intuitively, the higher debt levels correspond to higher risk premiums on domestic assets. For any given level of the money supply, the domestic real interest rate increases and, as a result, output falls below its natural level, increasing the output costs of maintenance. Since the fixed exchange rate is maintained, inflation and the monetary authorities' costs of inflation remain zero and thus play no role in equation (18).

### 3.2.2 Abandonment of the fixed exchange rate

Appendix 2B shows the derivation of the equilibrium in case of abandonment of the fixed exchange rate in period  $t$ . The costs of abandonment are shown to be equal to:

$$L_t^{CB} = \frac{\frac{\chi}{\eta}}{\frac{\chi}{\eta} + A^2} \left( A \cdot \pi^n + \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\hat{\phi}_t} \cdot c + \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t}}{\left( 1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)} \right) + k \right) \right)^2 \quad (19)$$

$$\text{where } A = \frac{(1 + \beta)}{\beta} \left( \frac{\lambda \left( 1 - \frac{\hat{d}_t^f}{\hat{\phi}_t} \right)}{\left( 1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)} + \theta \right)$$

The term for the output costs of maintenance in equation (18) also plays a role in the abandonment equilibrium, as can be seen from the second part between brackets in equation (19). The other part between brackets,  $A \cdot \pi^n$ , refers to the costs of inflation. Since period  $t$  monetary policy is now used to stimulate output, inflation in period  $t+1$  is no longer zero. Finally, the term before brackets,  $\frac{\chi}{\eta + A^2} < 1$ , shows that for  $\pi^n = 0$ , i.e. if inflation would be zero, the costs of abandonment would be lower than the costs of maintenance. This is because the output costs under abandonment are partly offset by a loosening of monetary policy that was not feasible under maintenance.

### 3.2.3 Maintenance or Collapse?

Equation (18) and (19) showed the costs of maintenance and abandonment of a fixed exchange rate regime, respectively. As long as the costs of maintenance do not exceed the costs of abandonment, the fixed exchange rate regime will survive. However, as soon as the costs of maintenance do exceed the costs of abandonment, the monetary authorities

will choose to abandon the peg and install a floating exchange rate. Appendix 2C shows that this will be the case if:

$$\Omega = \left( \sqrt{\frac{1}{A^2} + \frac{1}{\frac{\lambda}{\eta}}} - \frac{1}{A} \right) \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\phi_t} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\phi_t} \right)}{\left( 1 + \delta - \frac{\hat{d}_t^d}{\phi_t} \right)} \right) + k \right) - \pi^n > 0 \quad (20)$$

The function  $\Omega$  contains several variables that together determine whether the fixed exchange rate survives. In the next section we derive first-order derivatives to identify the effect of every variable on the probability of crisis, which we think of as positively depending on the size of  $\Omega$ .<sup>17</sup>

### 3.3 Determinants of currency crises

We first consider the impact of domestic and foreign currency denominated debt levels on the probability of collapse.

#### 3.3.1 Domestic and foreign debt levels

The first-order derivatives of the domestic debt level  $\frac{\hat{d}_t^d}{\phi_t}$  and the foreign debt level  $\frac{\hat{d}_t^f}{\phi_t}$ , as derived in Appendix 2D, have the following signs:

$$\begin{aligned} \frac{\partial \Omega}{\partial \left( \frac{\hat{d}_t^d}{\phi_t} \right)} &> 0 \\ \frac{\partial \Omega}{\partial \left( \frac{\hat{d}_t^f}{\phi_t} \right)} &\geq 0 \end{aligned} \quad (21)$$

The first derivative in equation (21) shows that a higher level of *domestic currency denominated debt* increases the probability of a currency crisis. As shown in Appendix 2D this is because the difference between the costs of maintenance and the costs of abandonment increases, which makes the abandonment of the fixed exchange rate relatively more attractive for the monetary authorities.

Intuitively, a higher domestic debt level increases the output costs under maintenance through a higher risk premium. The only way in which the monetary authorities can (partly) offset these higher output costs is by abandoning the fixed exchange rate and loosening monetary policy. This creates an incentive for the monetary authorities to abandon the fixed exchange rate. In addition, a higher domestic debt level also makes a loosening

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<sup>17</sup>Since we did not introduce any stochastic elements, the probability of crisis is strictly speaking either 1 or 0. However, it is easy to add for example a stochastic shock which would introduce the possibility of crisis probabilities between 0 and 1.

of monetary policy more effective in stimulating output. This is because corporates are more heavily exposed to interest rates and an interest rate cut thus has a larger negative effect on the risk premium.<sup>18</sup> Since the risk premium is part of the interest rate, the total decrease in the interest rate is larger and as a result the effect of monetary policy on output is also larger.

Higher domestic debt thus increases both the need for output loss compensation and the efficacy of monetary policy in stimulating output. The sum of these two effects dominates the increased costs of inflation<sup>19</sup> under abandonment. As a result, the difference between the costs of maintenance and the costs of abandonment increases. This creates incentives for the monetary authorities to abandon the fixed exchange rate. Hence, higher domestic debt increases the probability of a currency crisis.

The second derivative in equation (21) shows that a higher level of *foreign currency denominated debt* can either increase or decrease the probability of a currency crisis. As shown in Appendix 2D this is because the difference between the costs of maintenance and the costs of abandonment can either increase or decrease, depending on parameter values.

Intuitively, a higher foreign debt level increases the output costs under maintenance through a higher risk premium, just as in the case of domestic debt. Again, this creates an incentive for the monetary authorities to abandon the fixed exchange rate. However, whereas higher domestic debt makes monetary policy more effective in stimulating output, higher foreign debt has the opposite effect. Abandonment of the fixed exchange rate and a loosening of monetary policy lead to a depreciation of the nominal exchange rate. Given the higher corporate exposure to exchange rates, this depreciation has larger adverse effects on corporates' net worth. As a result, the risk premium increases more or decreases less. Since the risk premium is part of the interest rate, the total decrease in the interest rate will be smaller and the effect of monetary policy on output is thus also smaller.<sup>20</sup>

Higher foreign debt thus increases the need for output loss compensation but lowers the efficacy of monetary policy in stimulating output through the adverse balance sheet effects

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<sup>18</sup>Strictly speaking an interest rate cut can have a larger negative *or a smaller positive impact* on the risk premium. This is because a loosening of monetary policy can also lead to a higher risk premium if the investment effect dominates (see equation (76)). However, the total change in the interest rate after a loosening of monetary policy is always negative (see equation (79)). Hence, higher domestic debt amplifies the effect of monetary loosening on the interest rate, regardless of whether the risk premium goes up or down.

<sup>19</sup>It can be shown that the costs of inflation under abandonment increase. Intuitively, this is because the increased incentives to compensate for output loss lead to a looser monetary policy stance that stimulates output but comes at the cost of higher inflation.

<sup>20</sup>From equation (79) and given that  $\frac{\partial f}{\partial \phi_t} \leq 1$  it follows that the increase in the risk premium will never exceed the effect on the other components of the real interest rate. As a result, a loosening of monetary policy will always lead to a net decrease in the real interest rate.



of exchange rate depreciation. As a result, the sign of the net effect of higher foreign debt on the difference between the costs of maintenance and abandonment depends on parameter values. Hence, the sign of the impact of higher foreign debt on the probability of a currency crisis depends on the same parameter values.

### 3.3.2 Other variables

Appendix 2D also shows the effect of changes in the other model variables on the probability of crisis. First, an increase in the *monetary authorities' degree of conservativeness*  $\chi$  can either increase or decrease the probability of a currency crisis. This is because the costs of abandonment can increase or decrease, whereas the costs of maintenance do not change. Intuitively, the change in the costs of abandonment consists of a change in the output costs and a change in the costs of inflation. On the one hand, the inflation that arises from a loosening of monetary policy is valued more negatively by the monetary authorities. This makes the use of monetary policy to stimulate output more costly. As a result, the output loss is less compensated for and hence the output costs in the abandonment equilibrium increase.

On the other hand, however, the total costs of inflation go down. This is because the increase in the money supply and thus the part of inflation that follows from it will be smaller as inflation is valued more negatively. Moreover, the inflationary bias also goes down as the monetary authorities have less of an incentive to stimulate output through surprise inflation. These negative effects on the level of inflation more than offset the increased negative valuation of inflation. As a result, the total costs of inflation, equal to the level of inflation multiplied by the valuation of inflation (degree of conservativeness) by the monetary authorities, decrease. With the output costs increasing and the inflation costs decreasing, the sign of the total impact on the costs of abandonment depends on parameter values.

Analogues to the degree of conservatism, a higher increase in the *monetary authorities' rate of time preference*  $\eta$  can also either increase or decrease the probability of a currency crisis. The effect of a higher rate of time preference is exactly opposite to the effect of an increase in conservatism. This is because the rate of time preference in our model only relates to the difference in valuation between inflation (period  $t+1$ ) and output loss (period  $t$ ). Hence, a higher time preference implies that the level of inflation in period  $t$  is valued less negatively compared to the output loss in period  $t$ . As a result, the effect of higher time preference is similar to the effect of lower conservatism.

Next, an increase in the *wedge between the output level targeted by the monetary authorities and the natural output level*,  $k$ , is shown to either increase or decrease the probability of a currency crisis. On the one hand, a higher level of targeted output increases the

output costs for any given level of output under maintenance. These higher output costs can be (partly) offset by an abandonment of the fixed exchange rate and a loosening of monetary policy. This creates an incentive to abandon the fixed exchange rate. On the other hand, however, a higher output target increases the inflationary bias because the monetary authorities are more inclined to generate surprise inflation in order to stimulate output. This creates an incentive to maintain the fixed exchange rate under which inflation remains zero.

The effect of the *natural domestic real interest rate*  $r_n (= c)$  is straightforward. A higher natural domestic real interest rate lowers firms' net worth. This leads to a higher risk premium and lower output. Hence, the costs of maintenance increase and the only way to partly offset the higher output costs is an abandonment of the fixed exchange rate and a loosening of monetary policy. This creates an incentive to abandon the fixed exchange rate and thus increases the probability of a currency crisis.

A higher *interest rate elasticity of investment*,  $\delta$ , means a lower level of investment for any level of the real interest rate that exceeds the natural domestic real interest rate (see equation (14)). This lower investment level decreases the risk premium and hence decreases the output costs under maintenance. This creates an incentive for the monetary authorities to maintain the fixed exchange rate, as there is less need for output compensation. In addition, a higher interest rate elasticity of investment also makes monetary policy less effective in stimulating output. This is because an interest rate cut will have a larger positive impact on investments, which everything else equal increases the risk premium. Since the risk premium is part of the interest rate, the total decrease in the interest rate is smaller and as a result the effect of monetary policy on output is also smaller.

A higher *interest rate elasticity of investment* thus decreases both the need for output loss compensation and the efficacy of monetary policy in stimulating output. The sum of these two effects dominates the lower costs of inflation under abandonment that follow from the smaller incentive to stimulate output. As a result, the difference between the costs of maintenance and the costs of abandonment becomes smaller. This creates incentives for the monetary authorities to maintain the fixed exchange rate. Hence, a higher interest rate elasticity of investment decreases the probability of a currency crisis.

Next, an increase in the *real exchange rate elasticity of output*,  $\theta$ , is shown to either increase or decrease the probability of a currency crisis. On the one hand, monetary policy becomes more effective in stimulating output because the depreciation that follows from a monetary loosening has a larger positive impact on output. This creates an incentive to abandon the fixed exchange rate. On the other hand, a higher real exchange rate elasticity of output increases the inflationary bias as the monetary authorities are more inclined to loosen monetary policy in order to stimulate output through a depreciated exchange rate.

This creates an incentive to maintain the fixed exchange rate under which inflation remains zero.

A higher *real interest rate elasticity of output*,  $\lambda$ , also either increases or decreases the probability of crisis. On the one hand, for non-zero domestic or foreign debt, the output costs of maintenance increase through the higher negative impact of the interest rate on investments and output. This creates an incentive for the monetary authorities to abandon the fixed exchange rate. In addition, a higher real interest rate elasticity of output also makes a loosening of monetary policy more effective in stimulating output. This is because the drop in the interest rate that follows the loosening of monetary policy has a larger positive impact on output. This adds to the incentive for abandonment. However, a higher interest rate elasticity of output also increases the inflationary bias because monetary policy becomes more effective and hence the monetary authorities will be more inclined to use it. The increased inflationary bias creates an incentive to maintain the fixed exchange rate.

Finally, a higher *nominal interest rate elasticity of money demand*,  $\beta$ , either increases or decreases the probability of crisis. A higher  $\beta$  means that after an increase in the money supply the interest rate does not have to fall by as much as before in order to restore money market equilibrium (see Equation (1)). Hence, monetary policy becomes less effective in stimulating output, creating an incentive for monetary authorities to maintain the fixed exchange rate. On the other hand, the lower efficacy of monetary policy also leads to a lower inflationary bias as the monetary authorities are less inclined to loosen monetary policy. This creates an incentive to abandon the fixed exchange rate.

## 4 Summary and conclusions

This paper has studied how the exposure of a country's corporate sector to interest rate and exchange rate changes affects the decision of monetary authorities to maintain or abandon a fixed exchange rate. If corporate balance sheets are vulnerable to high interest rates, monetary authorities are less inclined to maintain a fixed exchange rate regime. However, if corporate balance sheets are instead vulnerable to depreciations of the exchange rate, this may urge monetary authorities to hold on to a fixed exchange rate to avoid adverse balance sheet effects.

These issues were analyzed using a model in which the monetary authorities are assumed to care about output and inflation. Currency crises were defined as situations in which the costs of maintaining a fixed exchange rate exceed the costs of abandonment. The impact of corporate exposures on the probability of crises was investigated by looking at the effect of aggregate debt levels on both the costs of maintenance and the costs of abandonment.

The results showed that a higher level of *domestic currency denominated debt* increases

the probability of a currency crisis. This is because higher domestic debt implies a lower level of firms' net worth which increases the risk premium they pay on external funds. This higher risk premium leads to lower investments and lower output. Monetary authorities can use monetary policy to limit output losses but they can only do so by abandoning the fixed exchange rate. Hence, increased output losses create an incentive for the monetary authorities to abandon the fixed exchange rate. However, higher domestic debt not only increases the monetary authorities' urge to use monetary policy to stimulate output. It also increases the efficacy of monetary policy in stimulating output. This is because the higher exposure to interest rate changes means that a loosening of monetary policy has a larger positive impact on corporate balance sheets and leads to a lower risk premium. This lower risk premium adds to the conventional effect of an increase in the money supply and hence increases the total effect of monetary policy on output. This increased efficacy of monetary policy adds to the incentive to abandon the fixed exchange rate since abandonment is the only way in which monetary policy can be used to boost output. It was shown that the higher need for output loss compensation and the higher efficacy of monetary policy in stimulating output together dominate the effect of higher inflation on incentives. As a result, higher domestic debt increases the probability of a currency crisis.

We next showed that a higher level of *foreign currency denominated debt* can either increase or decrease the probability of a currency crisis. Analogues to the case of domestic debt, higher foreign debt increases the costs of maintenance through a higher risk premium and lower output. Since the monetary authorities want to compensate for these output losses, they face an incentive to abandon the fixed exchange rate. However, whereas higher domestic debt increases the effect of monetary policy on output, higher foreign debt does the opposite. An increase in the money supply leads to a lower interest rate and a depreciation of the exchange rate. As corporates are more exposed to exchange rate changes, this depreciation has larger adverse effects on corporates' net worth and thus on the risk premium they pay. This higher risk premium partly cancels the conventional effect of monetary policy on output and hence decreases the efficacy of monetary policy. This lower efficacy creates an incentive to maintain the fixed exchange rate as the benefits from abandonment decrease, everything else equal. Higher foreign debt thus increases the need for output loss compensation but lowers the efficacy of monetary policy in stimulating output through the adverse balance sheet effects of exchange rate depreciation. As a result, the sign of the net effect of higher foreign debt on the probability of crisis was shown to depend on the model's parameter values.

Finally, the impact of several other possible crisis determinants on the probability of crises was analyzed.

The analysis in this paper shows that corporate balance sheet vulnerabilities can be an

important determinant of currency crises by eroding the commitment of monetary authorities to defend a fixed exchange rate regime. If countries want to reduce the probability and output costs of currency crises, it is recommendable to limit the exposure of their corporate and banking sectors to changes in the short-term interest rate and the exchange rate. This might for example be accomplished by further developing local equity markets in emerging market countries. Such markets reduce the leverage of corporates by allowing them to finance themselves through the stock market rather than solely through banks or bond markets. Equity provides a more *permanent* source of finance, as opposed to for example bank lending, which is in most cases short-term and thus needs to be rolled over. It has also shown to be a relatively *resilient* source of new financing during the Asian crisis. Both of these characteristics make corporates that finance themselves through equity more resistant against short-term interest rate increases and/or a sudden stop of bank lending (credit crunch).<sup>21</sup> Financial supervision and regulation can also reduce the exposures of banks and corporates. Requirements as to how much reserve capital banks and corporates should hold, how much short-term funding they may obtain, and how much of their liabilities can be in foreign currency, could provide some safeguards against the risk of crises and the social externalities that go with them.

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<sup>21</sup>IMF (2002).

## Appendix 1 Discretionary long-run equilibrium

To derive the period  $t$  equilibrium, we first consider period  $t-1$ , period  $t$ , and period  $t+1$ .

### Period $t-1$

Recalling equation (4), the domestic  $t-1$  interest rate is given by:

$$i_{t-1} = i^* + S_t - S_{t-1} + RP_{t-1} \quad (22)$$

The foreign nominal interest rate equals  $c$ . Given purchasing power parity in all periods and perfect foresight,  $S_t - S_{t-1}$  equals  $\pi^n$ . Furthermore, since the domestic economy is in long-run equilibrium, the absolute domestic risk premium equals the absolute foreign risk premium ( $=0$ ). Recalling (14), this implies that the domestic real interest rate and the debt ratios<sup>22</sup> equal their long-run equilibrium levels. As a consequence,  $RP_{t-1} = 0$ . Equation (22) can be rewritten as:

$$i_{t-1} = c + \pi^n \quad (23)$$

This yields the following money market equilibrium (equation (1)):

$$M_{t-1} - p_{t-1} = \gamma - \beta (c + \pi^n) \quad (24)$$

### Period $t$

The price level in period  $t$  simply equals the sum of the  $t-1$  price level and the natural inflation rate:

$$p_t = p_{t-1} + \pi^n \quad (25)$$

Money market equilibrium in period  $t$  is similar to equation (1)<sup>23</sup>, with  $RP_t = 0$ .

$$M_t = p_t + \gamma - \beta \cdot i_t \quad (26)$$

Substituting (24) and (25) into (26) yields:

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<sup>22</sup>For simplicity, we assume the long-run equilibrium debt ratios to be equal to zero.

<sup>23</sup>In equation 1 the price level was denoted as fixed. We assume, throughout this paper, that the price level cannot be adjusted throughout period  $t$ . However, the price level in equation 1 was assumed to be fixed as long as the fixed exchange rate regime was maintained. Here, monetary policy is discretionary and the price level changes every period.

$$M_t = M_{t-1} + \pi^n - \beta(i_t - c - \pi^n) \quad (27)$$

(27) shows how the existence of rational expectations influences the money market equilibrium. First of all, the nominal money supply in period  $t$  has to exceed the level in the previous period in order to keep up with the expected ‘natural rate of inflation’ ( $\pi^n$ ). In addition, deviations of the money supply from its long-run equilibrium supporting value correspond to deviations of  $i_t$  from its equilibrium value  $c + \pi^n$ .

## Period $t+1$

We assume that in period  $t+1$  the economy is in long-run equilibrium:

$$M_{t+1} - p_{t+1} = \gamma - \beta(c + \pi^n) \quad (28)$$

Since the period  $t+1$  price level is set to ensure that output will be at its natural level, it equals the sum of the price level that supports the equilibrium, given the period  $t$  money supply, and the natural rate of inflation:

$$p_{t+1} = \pi^n + M_t - \gamma + \beta(c + \pi^n) \quad (29)$$

## Equilibrium

Rewriting equation (26) yields the following expression for the period  $t$  price level.

$$p_t = M_t - \gamma + \beta \cdot i_t \quad (30)$$

For the level of inflation in period  $t+1$  this implies:

$$p_{t+1} - p_t = \pi^n + \beta(c + \pi^n - i_t) \quad (31)$$

Rewriting equation (27) yields:

$$i_t = -\frac{(M_t - M_{t-1} - \pi^n)}{\beta} + c + \pi^n \quad (32)$$

Substituting (32) into (31) and rearranging yields:

$$p_{t+1} - p_t = M_t - M_{t-1} \quad (33)$$

Equation (33) defines the first part of the monetary authorities’ loss function in terms of the money supply  $M_t$ . Turning to the second part of the monetary authorities’ loss function, the effect of monetary policy on output in period  $t$  runs through the real interest rate,  $r_t$ , and through the nominal exchange rate,  $S_t$ .

$$y_t = y_n - \lambda (r_t - r_n) + \theta (S_t - p_t) \quad (34)$$

We first consider the ‘interest rate channel’,  $-\lambda (r_t - r_n)$ . Recall (32):

$$i_t = -\frac{(M_t - M_{t-1} - \pi^n)}{\beta} + c + \pi^n \quad (35)$$

Also recall that:

$$i_t = r_t + \dot{p}_{t+1} = r_t + M_t - M_{t-1} \quad (36)$$

Substituting (36) in (35) and rearranging yields:

$$r_t = -\frac{1+\beta}{\beta} (M_t - M_{t-1} - \pi^n) + c \quad (37)$$

Turning to the exchange rate effect of monetary policy on output in period t,  $S_t - p_t$ , recall equation (4):

$$i_t = i^* + (S_{t+1} - S_t) + RP_t \quad (38)$$

With  $RP_t = 0$  and  $i^* = c$ , (38) can be rewritten as:

$$S_t = S_{t+1} - (i_t - c) \quad (39)$$

Recall that we assumed long-run equilibrium in period t+1, where purchasing power parity holds. Consequently,  $S_{t+1}$  equals  $p_{t+1}$ . Subtracting  $p_t$  yields:

$$S_t - p_t = p_{t+1} - p_t - (i_t - c) \quad (40)$$

Substituting (32) and (33) in (40) yields:

$$S_t - p_t = M_t - M_{t-1} - \left( -\frac{(M_t - M_{t-1} - \pi^n)}{\beta} + \pi^n \right) = \frac{1+\beta}{\beta} (M_t - M_{t-1} - \pi^n) \quad (41)$$

We can now write the monetary authorities’ loss function in terms of the nominal money supply and solve for the optimal level of the money supply.

Recall from (2) and (15) that:

$$L_t^{CB} = \frac{\chi}{\eta} \dot{p}_{t+1}^2 + (-\lambda (r_t - r_n) + \theta (S_t - p_t) - k)^2 \quad (42)$$

Substituting the results in (33), (37), and (41) in (42) yields:

$$L_t^{CB} = \frac{\chi}{\eta} (M_t - M_{t-1})^2 + \left( (\lambda + \theta) \left( \frac{1+\beta}{\beta} \right) (M_t - M_{t-1} - \pi^n) - k \right)^2 \quad (43)$$



Minimization of the monetary authorities' loss function in terms of the money supply yields the optimal level of the money supply:

$$M_t = M_{t-1} + \frac{X^2}{\frac{X}{\eta} + X^2} \cdot \pi^n + \frac{X}{\frac{X}{\eta} + X^2} \cdot k, \text{ where } X = (\lambda + \theta) \left( \frac{1 + \beta}{\beta} \right) \quad (44)$$

The inflationary bias,  $\pi^n$ , can now be made explicit. We assumed perfect foresight, hence:

$$\pi^n = \dot{p}_{t+1} = M_t - M_{t-1} \quad (45)$$

Substituting (45) into (44) and solving for  $M_t$  yields:

$$M_t = M_{t-1} + \frac{X}{\frac{X}{\eta}} \cdot k \quad (46)$$

(45) and (46) imply the following for the inflationary bias:

$$\pi^n = \frac{X}{\left( \frac{X}{\eta} \right)} \cdot k \quad (47)$$

## Appendix 2 Equilibria under an initially fixed exchange rate

### A Maintenance of the fixed exchange rate

Again, we consider periods  $t-1$ ,  $t$ , and  $t+1$ , but now under the assumption that the monetary authorities have been running a fixed exchange rate in period  $t-1$  and continue to do so in period  $t$  and  $t+1$ .

#### Period $t-1$

Assuming long-run equilibrium, the risk premium is assumed to be zero ( $RP_{t-1} = 0$ ). Furthermore, since the monetary authorities maintain the peg, the exchange rate remains constant. Consequently, equation (4) can be reduced to:

$$i_{t-1} = c \quad (48)$$

For the money market equilibrium this implies the following:

$$M_{t-1} - \bar{p}_{t-1} = \gamma - \beta \cdot c \quad (49)$$

### Period t

Assuming a fixed exchange rate and allowing for deviations of debt levels from their natural levels, equation (4) can be reduced to:

$$i_t = c + RP_t \quad (50)$$

Money market equilibrium now implies:

$$M_t = \bar{p}_t + \gamma - \beta \cdot c \quad (51)$$

and, since the price level has not changed:

$$M_t = M_{t-1} \quad (52)$$

### Period t+1

Under the assumptions that the fixed exchange rate is maintained throughout period t and the debt levels return to their natural levels, the equilibrium in period t is similar to the period t-1 equilibrium:

$$i_{t+1} = c \quad (53)$$

Since the price level has not changed, money market equilibrium is identical to period t-1:

$$M_{t+1} - \bar{p}_{t+1} = \gamma - \beta \cdot c \quad (54)$$

### Equilibrium

Since we have assumed that the monetary authorities maintain the peg, we can calculate the costs of maintenance from the monetary authorities' loss function:

$$L_t^{CB} = \frac{\chi}{\eta} \bar{p}_{t+1}^2 + (-\lambda (r_t - r_n) + \theta (S_t - p_t) - k)^2 \quad (55)$$

As shown above, the price level remains fixed. Consequently, period t+1 inflation equals zero. Moreover, the level of the exchange rate also remains fixed. Given the assumption of purchasing power parity in period t-1, this implies that the period t price level equals the period t level of the exchange rate. Equation (55) can therefore be reduced to:

$$L_t^{CB} = (-\lambda (r_t - r_n) - k)^2 \quad (56)$$

Since inflation is zero, the domestic real interest rate equals the domestic nominal interest rate.

$$r_t = i_t = c + RP_t \quad (57)$$

Substituting (14) into (57) yields:

$$r_t = c - \delta (r_t - r_n) + (1 + r_t) \frac{\hat{d}_t^d}{\hat{\phi}_t} + (1 + S_t - S^{fix}) \frac{\hat{d}_t^f}{\hat{\phi}_t} \quad (58)$$

For  $S_t - S^{fix} = 0$ , rearranging yields:

$$r_t = \frac{(1 + \delta) \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t} \right)}{\left( 1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)} \quad (59)$$

For the costs of maintenance (56) this implies:

$$L_t^{CB} = \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\hat{\phi}_t} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t} \right)}{\left( 1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)} + k \right)^2 \quad (60)$$

## B Abandonment of the fixed exchange rate

We now consider the case where the monetary authorities abandon the fixed exchange rate in period  $t$ . Period  $t-1$  is unchanged.

### Period $t$

By abandoning the peg, the monetary authorities regain their monetary policy autonomy and set the money supply so as to minimize their loss function. Given the possible deviation of debt levels in period  $t$ , money market equilibrium denotes the following:

$$M_t - \bar{p}_t = \gamma - \beta(i_t - RP_t) \quad (61)$$

Given that  $\bar{p}_t = \bar{p}_{t-1}$ , (61) can be rewritten as:

$$(i_t - RP_t) = -\frac{(M_t - \bar{p}_t - \gamma)}{\beta} = -\frac{(M_t - M_{t-1})}{\beta} + c \quad (62)$$

Recall equation (4) for the revised uncovered interest parity condition:

$$i_t = i^* + (S_{t+1} - S_t) + RP_t \quad (63)$$

## Period t+1

We assume that, given the abandonment of the fixed exchange rate in period t, the economy will adjust to its new long-run equilibrium in period t+1. Therefore, the t+1 price level equals the equilibrium level in case the money supply stays at its period t level, plus the anticipated money supply change<sup>24</sup>.

$$p_{t+1} = \pi^n + M_t - \gamma + \beta (c + \pi^n) \quad (64)$$

Further, the money market equilibrium and uncovered interest parity equations are given by:

$$M_{t+1} - p_{t+1} = \gamma - \beta(c + \pi^n) \quad (65)$$

$$i_{t+1} = c + \pi^n \quad (66)$$

## Equilibrium

We calculate the costs of abandonment according to the monetary authorities' loss function:

$$L_t^{CB} = \frac{\chi}{\eta} \bar{p}_{t+1}^2 + (-\lambda (r_t - r_n) + \theta (S_t - \bar{p}_t) - k)^2 \quad (67)$$

Starting with inflation, combining (61) and (64) yields:

$$p_{t+1} - \bar{p}_t = \pi^n + M_t - \gamma + \beta (c + \pi^n) - M_t + \gamma - \beta(i_t - RP_t) = \pi^n - \beta(i_t - RP_t - (c + \pi^n)) \quad (68)$$

Substituting (62) in (68) yields:

$$p_{t+1} - \bar{p}_t = (1 + \beta) \pi^n + M_t - M_{t-1} \quad (69)$$

Turning to the second part of the monetary authorities' loss function, the effect of monetary policy on output in period t runs through the real interest rate,  $r_t$ , and through the nominal exchange rate,  $S_t$ .

$$y_t = y_n - \lambda (r_t - r_n) + \theta (S_t - \bar{p}_t) \quad (70)$$

We will first consider the 'interest rate channel'. Recall (62):

$$i_t = -\frac{(M_t - M_{t-1})}{\beta} + c + RP_t \quad (71)$$

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<sup>24</sup>Recall that this anticipated change simply equals the level of the inflationary bias, as derived in Appendix 1.

Equation (14) defined the risk premium:

$$RP_t = -\delta(r_t - r_n) + (1 + r_t) \frac{\hat{d}_t^d}{\hat{\phi}_t} + (1 + S_t - S^{fix}) \frac{\hat{d}_t^f}{\hat{\phi}_t} \quad (72)$$

The term  $S_t - S^{fix}$  is not exogenous as it is depending on the interest rate. Rewriting equation (4) yields:

$$S_t = -(i_t - RP_t - i^*) + S_{t+1} \quad (73)$$

Given  $i^* = c$  and  $S_{t+1} = p_{t+1}$ , and substituting (62), (73) can be written as:

$$S_t = \frac{(M_t - M_{t-1})}{\beta} + p_{t+1} \quad (74)$$

Recall that  $S^{fix} = \bar{p}_t$ ; substituting (69) for the level of inflation yields:

$$S_t - S^{fix} = \frac{(M_t - M_{t-1})}{\beta} + p_{t+1} - \bar{p}_t = \frac{(1 + \beta)}{\beta} (M_t - M_{t-1} + \beta \cdot \pi^n) \quad (75)$$

Substituting (75) in (72) yields the following:

$$RP_t = -\delta(r_t - r_n) + (1 + r_t) \frac{\hat{d}_t^d}{\hat{\phi}_t} + \left(1 + \frac{(1 + \beta)}{\beta} (M_t - M_{t-1} + \beta \cdot \pi^n)\right) \frac{\hat{d}_t^f}{\hat{\phi}_t} \quad (76)$$

Substituting this result into (71):

$$\begin{aligned} i_t = & -\frac{(M_t - M_{t-1})}{\beta} + c - \delta(r_t - r_n) + (1 + r_t) \frac{\hat{d}_t^d}{\hat{\phi}_t} \\ & + \left(1 + \frac{(1 + \beta)}{\beta} (M_t - M_{t-1} + \beta \cdot \pi^n)\right) \frac{\hat{d}_t^f}{\hat{\phi}_t} \end{aligned} \quad (77)$$

Recall that, once period t monetary policy is known, the t+1 level of inflation and, consequently, the period t real interest rate is also known.

$$i_t = r_t + \dot{p}_{t+1} = r_t + (1 + \beta) \pi^n + (M_t - M_{t-1}) \quad (78)$$

Combining (77) and (78), and rearranging yields:

$$r_t = \frac{(1 + \delta) \cdot c + \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t}}{\left(1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t}\right)} - \frac{(1 + \beta)}{\beta} \frac{\left(1 - \frac{\hat{d}_t^f}{\hat{\phi}_t}\right)}{\left(1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t}\right)} (M_t - M_{t-1} + \beta \cdot \pi^n) \quad (79)$$

Turning to the exchange rate effect of monetary policy on output in period t,  $S_t - p_t$  ( $= S_t - S^{fix}$ ), recall equation (75):

$$S_t - p_t = \frac{(1 + \beta)}{\beta} (M_t - M_{t-1} + \beta \cdot \pi^n) \quad (80)$$

Using (69), (79), and (80), we can now write the monetary authorities' loss function (67) in terms of the nominal money supply and solve for the optimal level.

$$\begin{aligned} L_t^{CB} &= \frac{\chi}{\eta} ((1 + \beta) \pi^n + M_t - M_{t-1})^2 \\ &\quad + \left( -\lambda \left( \frac{\frac{\hat{d}_t^d}{\hat{\phi}_t} \cdot c + \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t}}{\left(1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t}\right)} \right) + A(M_t - M_{t-1} + \beta \cdot \pi^n) - k \right)^2 \quad (81) \\ \text{where } A &= \frac{(1 + \beta)}{\beta} \left( \frac{\lambda \left(1 - \frac{\hat{d}_t^f}{\hat{\phi}_t}\right)}{\left(1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t}\right)} + \theta \right) \end{aligned}$$

Minimization of the monetary authorities' loss function in terms of the money supply yields the optimal level of the money supply:

$$M_t = M_{t-1} - \left( \beta + \frac{\frac{\chi}{\eta}}{\frac{\chi}{\eta} + A^2} \right) \pi^n + \frac{A}{\frac{\chi}{\eta} + A^2} \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\hat{\phi}_t} \cdot c + \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t}}{\left(1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t}\right)} \right) + k \right) \quad (82)$$

Substituting the optimal money supply into (81) and rearranging yields:

$$L_t^{CB} = \frac{\frac{\chi}{\eta}}{\frac{\chi}{\eta} + A^2} \left( A \cdot \pi^n + \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\hat{\phi}_t} \cdot c + \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t}}{\left(1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t}\right)} \right) + k \right) \right)^2 \quad (83)$$

## C Maintenance or Collapse?

The monetary authorities will abandon the fixed exchange rate regime if the costs of maintenance exceed the costs of abandonment. Recalling equation (18) and (19), this implies:

$$\begin{aligned} &\left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\hat{\phi}_t} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t} \right)}{\left(1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t}\right)} \right) + k \right)^2 \\ &> \frac{\frac{\chi}{\eta}}{\frac{\chi}{\eta} + A^2} \left( A \cdot \pi^n + \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\hat{\phi}_t} \cdot c + \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t}}{\left(1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t}\right)} \right) + k \right) \right)^2 \quad (84) \end{aligned}$$

The inequality in equation (84) can be rearranged as:

$$\left( \sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} - \frac{1}{A} \right) \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\hat{\phi}_t} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t} \right)}{\left( 1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)} \right) + k \right) - \pi^n > 0 \quad (85)$$

Hereafter, we define the left-hand side of (85) as  $\Omega$ .

## D Crisis determinants

### Domestic debt level

The first-order derivative of  $\Omega$  in terms of the domestic debt level is given by:

$$\begin{aligned} \frac{\partial \Omega}{\partial \left( \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)} = & \left( -\frac{1}{\sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} \cdot A^3} + \frac{1}{A^2} \right) \cdot \left( \frac{(1 + \beta) \lambda \left( 1 - \frac{\hat{d}_t^f}{\hat{\phi}_t} \right)}{\beta \left( 1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)^2} \right) \\ & \cdot \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\hat{\phi}_t} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t} \right)}{\left( 1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)} \right) + k \right) \\ & + \left( \sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} - \frac{1}{A} \right) \cdot \frac{\lambda \left( (1 + \delta) (1 + c) + \frac{\hat{d}_t^f}{\hat{\phi}_t} \right)}{\left( 1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)^2} \end{aligned} \quad (86)$$

All right-hand side parts are positive. As a result:

$$\frac{\partial \Omega}{\partial \left( \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)} > 0 \quad (87)$$

### Foreign debt level

The first-order derivative of  $\Omega$  in terms of the foreign debt level is given by:

$$\begin{aligned} \frac{\partial \Omega}{\partial \left( \frac{\hat{d}_t^f}{\hat{\phi}_t} \right)} = & \left( -\frac{1}{\sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} \cdot A^3} + \frac{1}{A^2} \right) \cdot \left( -\frac{(1 + \beta) \lambda}{\beta \left( 1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)} \right) \\ & \cdot \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\hat{\phi}_t} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\hat{\phi}_t} \right)}{\left( 1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)} \right) + k \right) \\ & + \left( \sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} - \frac{1}{A} \right) \cdot \frac{\lambda}{\left( 1 + \delta - \frac{\hat{d}_t^d}{\hat{\phi}_t} \right)} \geq 0 \end{aligned} \quad (88)$$

## Other variables

$$\frac{\partial \Omega}{\partial \frac{\chi}{\eta}} = -\frac{1}{2\sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}}} \cdot \frac{1}{\left(\frac{\chi}{\eta}\right)^2} \cdot \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\frac{\chi}{\eta}} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\frac{\chi}{\eta}} \right)}{\left(1 + \delta - \frac{\hat{d}_t^d}{\frac{\chi}{\eta}}\right)} \right) + k \right) + (\lambda + \theta) \left( \frac{1 + \beta}{\beta} \right) \frac{k}{\left(\frac{\chi}{\eta}\right)^2} \geq 0 \quad (89)$$

$$\frac{\partial \Omega}{\partial k} = \left( \sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} - \frac{1}{A} \right) - \frac{(\lambda + \theta)}{\left(\frac{\chi}{\eta}\right)} \left( \frac{1 + \beta}{\beta} \right) \geq 0 \quad (90)$$

$$\frac{\partial \Omega}{\partial c} = \left( \sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} - \frac{1}{A} \right) \cdot \left( \lambda \frac{\frac{\hat{d}_t^d}{\frac{\chi}{\eta}}}{\left(1 + \delta - \frac{\hat{d}_t^d}{\frac{\chi}{\eta}}\right)} \right) > 0 \quad (91)$$

$$\begin{aligned} \frac{\partial \Omega}{\partial \delta} = & \left( -\frac{1}{\sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} \cdot A^3} + \frac{1}{A^2} \right) \left( -\frac{(1 + \beta) \lambda \left(1 - \frac{\hat{d}_t^f}{\frac{\chi}{\eta}}\right)}{\beta \left(1 + \delta - \frac{\hat{d}_t^d}{\frac{\chi}{\eta}}\right)^2} \right) \cdot \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\frac{\chi}{\eta}} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\frac{\chi}{\eta}} \right)}{\left(1 + \delta - \frac{\hat{d}_t^d}{\frac{\chi}{\eta}}\right)} \right) + k \right) \\ & - \left( \sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} - \frac{1}{A} \right) \lambda \left( \frac{\frac{\hat{d}_t^d}{\frac{\chi}{\eta}} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\frac{\chi}{\eta}} \right)}{\left(1 + \delta - \frac{\hat{d}_t^d}{\frac{\chi}{\eta}}\right)^2} \right) < 0 \end{aligned} \quad (92)$$

$$\begin{aligned} \frac{\partial \Omega}{\partial \theta} = & \left( -\frac{1}{\sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} \cdot A^3} + \frac{1}{A^2} \right) \cdot \left( \frac{1 + \beta}{\beta} \right) \cdot \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\frac{\chi}{\eta}} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\frac{\chi}{\eta}} \right)}{\left(1 + \delta - \frac{\hat{d}_t^d}{\frac{\chi}{\eta}}\right)} \right) + k \right) \\ & - \left( \frac{1 + \beta}{\beta} \right) \frac{k}{\left(\frac{\chi}{\eta}\right)} \geq 0 \end{aligned} \quad (93)$$

$$\begin{aligned} \frac{\partial \Omega}{\partial \lambda} = & \left( -\frac{1}{\sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} \cdot A^3} + \frac{1}{A^2} \right) \frac{(1 + \beta)}{\beta} \left( \frac{\left(1 - \frac{\hat{d}_t^f}{\frac{\chi}{\eta}}\right)}{\left(1 + \delta - \frac{\hat{d}_t^d}{\frac{\chi}{\eta}}\right)} \right) \\ & \cdot \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\frac{\chi}{\eta}} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\frac{\chi}{\eta}} \right)}{\left(1 + \delta - \frac{\hat{d}_t^d}{\frac{\chi}{\eta}}\right)} \right) + k \right) + \left( \sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} - \frac{1}{A} \right) \cdot \left( \frac{\frac{\hat{d}_t^d}{\frac{\chi}{\eta}} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\frac{\chi}{\eta}} \right)}{\left(1 + \delta - \frac{\hat{d}_t^d}{\frac{\chi}{\eta}}\right)} \right) \\ & - \left( \frac{1 + \beta}{\beta} \right) \frac{k}{\left(\frac{\chi}{\eta}\right)} \geq 0 \end{aligned} \quad (94)$$

$$\begin{aligned} \frac{\partial \Omega}{\partial \beta} = & - \left( -\frac{1}{\sqrt{\frac{1}{A^2} + \frac{1}{\frac{\chi}{\eta}}} \cdot A^3} + \frac{1}{A^2} \right) \cdot \left( \frac{\lambda \left(1 - \frac{\hat{d}_t^f}{\frac{\chi}{\eta}}\right)}{\left(1 + \delta - \frac{\hat{d}_t^d}{\frac{\chi}{\eta}}\right)} + \theta \right) \cdot \frac{1}{\beta^2} \\ & \cdot \left( \lambda \left( \frac{\frac{\hat{d}_t^d}{\frac{\chi}{\eta}} \cdot c + \left( \frac{\hat{d}_t^d + \hat{d}_t^f}{\frac{\chi}{\eta}} \right)}{\left(1 + \delta - \frac{\hat{d}_t^d}{\frac{\chi}{\eta}}\right)} \right) + k \right) + \left( (\lambda + \theta) \frac{k}{\left(\frac{\chi}{\eta}\right)} \right) \frac{1}{\beta^2} \geq 0 \end{aligned} \quad (95)$$



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